FUNDAMENTALS OF CO_2 TRANSPORT – BUILDING ON THE CURRENT INFRASTRUCTURE TO MEET THE DEMANDS OF WIDELY DEPLOYED, COMMERCIAL SCALE CCS SYSTEMS*

Public Service Commission of Wisconsin
Carbon Sequestration Study Group

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Melzer CO_2nsulting

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CO_2 TRANSPORT
FOR COMMERCIAL SCALE CCS SYSTEMS

1) The Evolving Framework for CO_2 Pipeline Systems

2) Pipeline CO_2 Specifications

3) Existing Transportation (Pipeline) Models

4) The Future Challenge – Examples of Networks

5) Point-to-Point, Ownership and Open Access Issues

6) Facilitating the Pipelines – Government/Quasi Government and Commercial Facilitators

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SPECIAL ACKNOWLEDGEMENTS

- The Interstate Oil & Gas Compact Commission's Subcommittee on Carbon Capture and Sequestration (specifically the IOGCC and the Contributing Regulator Members)
- The US Department of Energy and the National Energy Technology Laboratory as Funding Agencies for the Above and for their Vision to the Future of Coal
- The Technology and Best Practices Sharing of the Oil and Gas Industry

THE EVOLVING FRAMEWORK

for CO_2 Pipeline Systems

Type I Special, Single Use Pipelines (Case-by-case Specifications for Carried Fluid Composition)

Type II The North American Network i.e., Multiple Source and User Lines (Strict Specified CO_2 Composition)

Type III Hybrid Lines (Relaxed but Controlled CO_2 Composition)

TYPE I
SPECIAL, SINGLE USE "CO_2" PIPELINES

- Does Not Attempt to Commoditize CO_2
- Minimizes Processing Cost of CO_2
- Specification of Carrier (Injectate) Fluid Could Vary Widely
- Would Most Often be a Short Run Pipeline Connecting Single Source to Single Sinks or Sink Clusters
- Common Source-to-Sink Ownership

No Current (High Volume) Operational Models for Type I CO_2 Pipelines

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Current CO_2 Pipeline Systems

(Emphasized Herein)

i.e., Commodity CO_2 Lines

Types II and III

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Type II

MULTIPLE SOURCE AND USER LINES (HIGH VALUE AND SPECIFIED CO_2 COMPOSITION)

- Designed to Connect Multiple Sources with Multiple Sinks
- Strict Specifications for CO_2
- Multiple Pipeline Interconnects
- Several Pipeline Models Exist Today that can/will Interconnect to Future Lines (Perhaps Evolving to a North American CO_2 Pipeline Network)

Type III
HYBRID CO_2 PIPELINES

- Can Include Multiple Sources and Multiple Sinks
- Locally Sink-Defined Specifications for CO_2
- Commodity Pipeline (Lower Value Carrier Fluid)
  - e.g., High H_2S, High N_2 (ECBM)
- Shorter Run Pipelines
- Possible Special Operational Safety Issues
  - e.g., High H_2S Concentrations

EXISTING TRANSPORTATION MODELS

The Major* North American CO_2 Pipelines

Ref: Melzer Consulting '07

PIPELINE	Owner/Operator	Length (mi)	Length (km)	Diameter - in	Estimated Max Flow Capacity (mmcfpd)	Estimated Max Flow Capacity (million tons/yr	Location	PL Type
Adair	Apache	15	24	4	47	1.0	TX	II
Anadarko Powder River Basin CO2 PL	Anadarko	125	201	16	204	4.3	WY	II
Anton Irish	Oxy	40	64	8	77	1.6	TX	II
Bravo	Oxy Permian	218	351	20	331	7.0	NM,TX	II
Canyon Reef Carriers	Kinder Morgan	139	224	16	204	4.3	TX	II
Centerline	Kinder Morgan	113	182	16	204	4.3	TX	II
Central Basin	Kinder Morgan	143	230	16	204	4.3	TX	II
Chaparral	Chaparral Energy	23	37	6	60	1.3	OK	II
Choctaw	Denbury Resources	183	294	20	331	7.0	MS,LA	II
Comanche Creek (2007 reactivated)	PetroSource	100	161	6	60	1.3	TX	II
Cordona Lake	XTO	7	11	6	60	1.3	TX	II
Cortez	Kinder Morgan	502	808	30	1117	23.6	TX	II
Dollarhide	Chevron	23	37	8	77	1.6	TX	II
El Mar	Kinder Morgan	35	56	6	60	1.3	TX	II
Enid-Purdy (Central Oklahoma)	Anadarko	117	188	8	77	1.6	OK	II
Este I - to Welch, Tx	ExxonMobil, et al	40	64	14	160	3.4	TX	II
Este II - to Salt Crk Field	ExxonMobil	45	72	12	125	2.6	TX	II
Ford	Kinder Morgan	12	19	4	47	1.0	TX	II
Joffre Viking	Penn West Petroleum Ltd.	8	13	6	60	1.3	Alberta	II
Llano	Trinity CO2	53	85	12-8	77	1.6	NM	II
Pecos County	Kinder Morgan	26	42	8	77	1.6	TX	II
Raven Ridge	Chevron	160	257	16	204	4.3	WY/Co	II
Sheep Mtn	British Petroleum	408	656	24	538	11.4	TX	II
Shute Creek	ExxonMobil	30	48	30	1117	23.6	WY	II
Slaughter	Oxy Permian	35	56	12	125	2.6	TX	II
Transpetco	TransPetco	110	177	8	77	1.6	TX,OK	II
W. Texas	Trinity CO2	60	97	12-8	77	1.6	TX,NM	II
Wellman	PetroSource	25	40	6	60	1.3	TX	II
White Frost	Core Energy, LLC	11	18	6	60	1.3	MI	II
Wyoming CO2	ExxonMobil	112	180	20-16	204	4.3	WY	II
Dakota Gasification (Souris Valley)	Dakota Gasification	204	328	16	204	4.3	ND/Sask	III
Pikes Peak	PetroSource	40	64	8	77	1.6	TX	III
Val Verde	PetroSource	83	134	10	98	2.1	TX	III
	Totals:	3,245	5,221					

* **Tabulation does not include many shorter high pressure trunk lines to indiividual fields**

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CO_2 PIPELINE SPECIFICATIONS

EXAMPLE 1 (Type II)

NATURAL SOURCE (COMPANY "X")
Permian Basin CO_2 Specifications

Gas specifications		
CO_2	95%	by volume
H_2S	<10	ppmbw
Sulphur	<35	ppmbw
Total Hydrocarbons	<5%	by volume
CH_4	-	not specified
C_2+ hydrocarbons	-	not specified
CO	-	not specified
N_2	<4%	by volume
O_2	<10	ppmbw
H_2O	<25	#/mmcf

* Personal Communications

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CO_2 PIPELINE SPECIFICATIONS

EXAMPLE 2 (Type II)

NATURAL SOURCE (COMPANY "Y") **Permian Basin CO_2 Specifications***		
Gas specifications		
CO_2	95%	by volume
H_2S	<20	ppm bw
Sulphur	<30	ppm bw
Total Hydrocarbons	<5%	mole %
CH_4	-	not specified
C_2+ hydrocarbons	-	not specified
CO	-	not specified
N_2	<4%	mole %
O_2	<10	ppm bw
H_2O	<30	#/mmcf

* Personal Communications

CO_2 PIPELINE SPECIFICATIONS

EXAMPLE 3 (Type III)

Dakota Gasification Corporation
WEYBURN PIPELINE

Gas specifications

CO_2	96%	by volume
H_2S	0.90%	
Sulphur	-	
Total Hydrocarbons	-	
CH_4	0.70%	
C_2+ hydrocarbons	2.30%	
CO	0.10%	
N_2	<300	ppmbv
O_2	<50	ppmbv
H_2O	<20	ppmbv

* Ref: http://www.apgtf-uk.com/15Jan03/pdf/09%20RILEY%20Transport%2015Jan03.pdf

SUMMARY OF CO_2 PIPELINE SPECIFICATIONS

Parameter	Example 1	Example 2	Example 3
CO_2 - % by volume	95%	95%	96%
H_2S - ppmbw	10	20	10,000
Sulphur - ppmbw	35	30	-
Total Hydrocarbons - % by volume	5	5	-
CH_4 - % by volume	-	-	700
C_2+ hydrocarbons - % by volume	-	-	23,000
CO - % by volume	-	-	1,000
N_2 - % by volume/wt	4	4	300
O_2 - ppm by wt/vol	10	10	50
H_2O - #/mmcf*or ppm by vol	25*	30*	20

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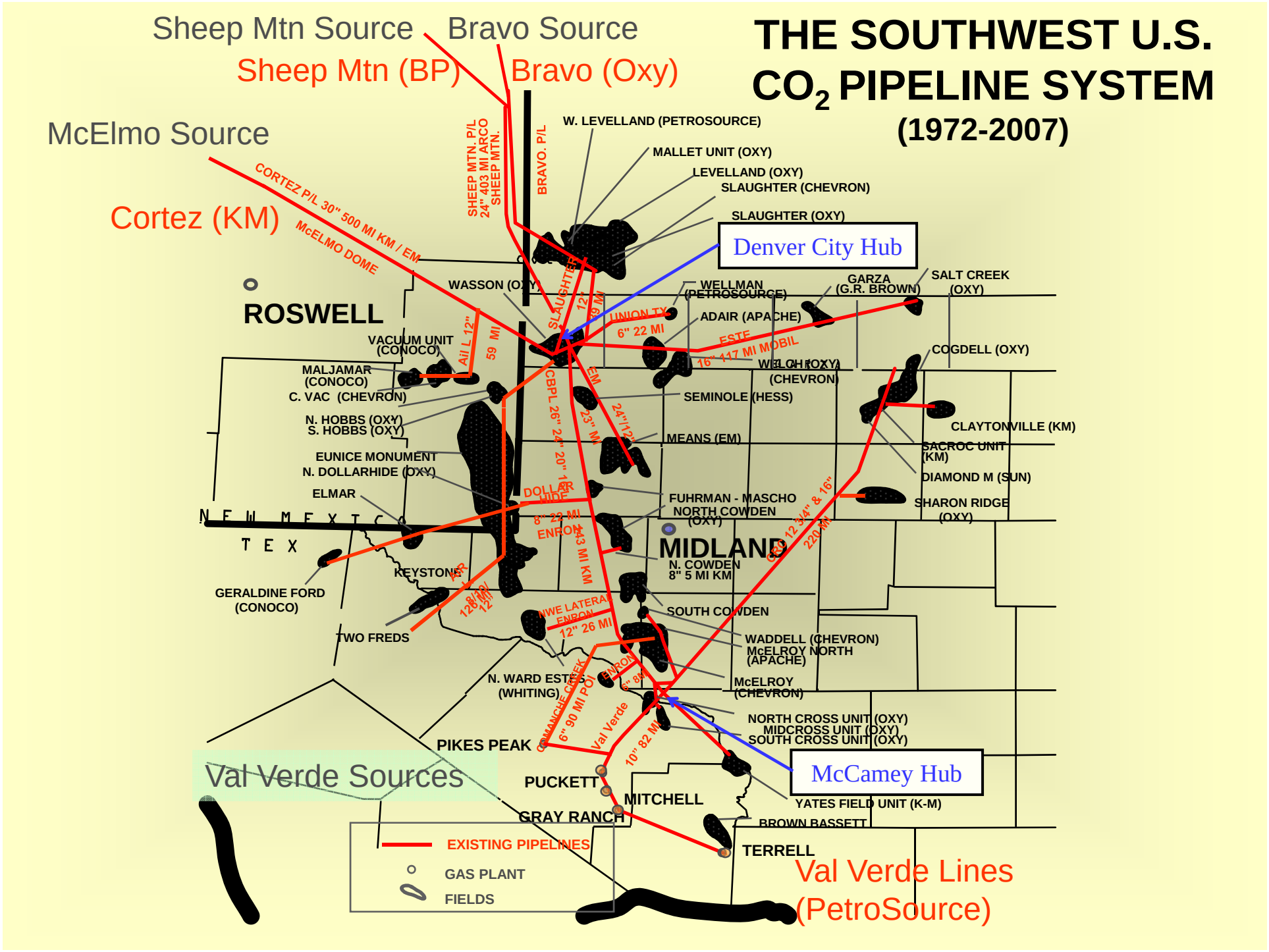
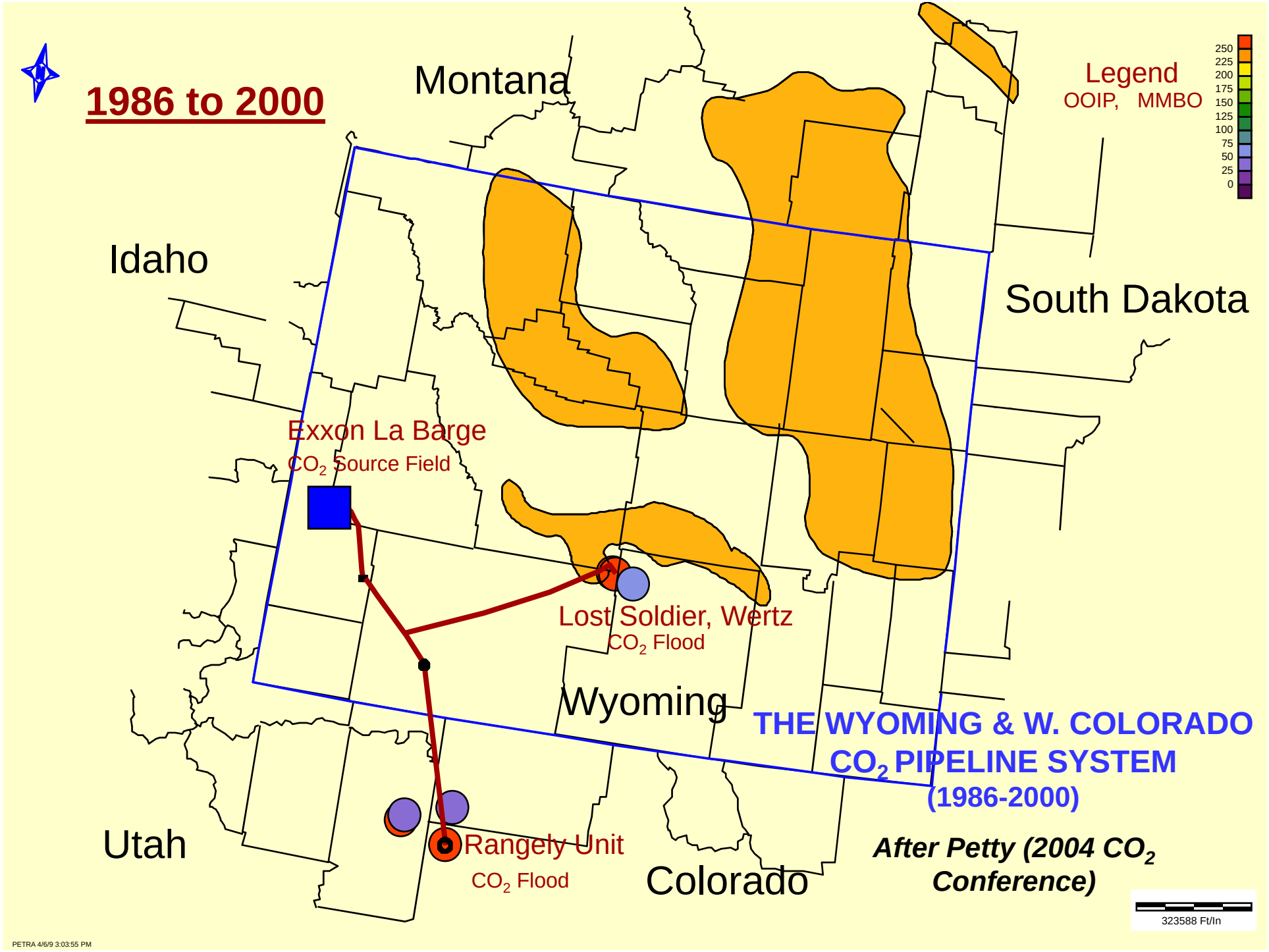
CONTAMINANT ISSUES
Affecting CO_2 Commodity Value

- Pipeline Corrosion (Water and Oxygen)
- Safety (e.g., H_2S)
- Dense (Critical) Phase Degradation
- Reservoir Microbial Activity (e.g., Oxygen)
- Oil Miscibility (Methane and Nitrogen)
- Enhanced Gas Recovery
- Others?

EXAMPLE NETWORKS
(EXISTING)



THE SOUTHWEST U.S. CO_2 PIPELINE SYSTEM (1972-2007)


1986 to 2000
Montana
Legend
OOIP, MMBO
250
225
200
175
150
125
100
75
50
25
0
Idaho
South Dakota
Exxon La Barge
CO_2 Source Field
Lost Soldier, Wertz
CO_2 Flood
Wyoming
THE WYOMING & W. COLORADO
CO_2 PIPELINE SYSTEM
(1986-2000)
Utah
Rangely Unit
CO_2 Flood
Colorado
After Petty (2004 CO_2 Conference)
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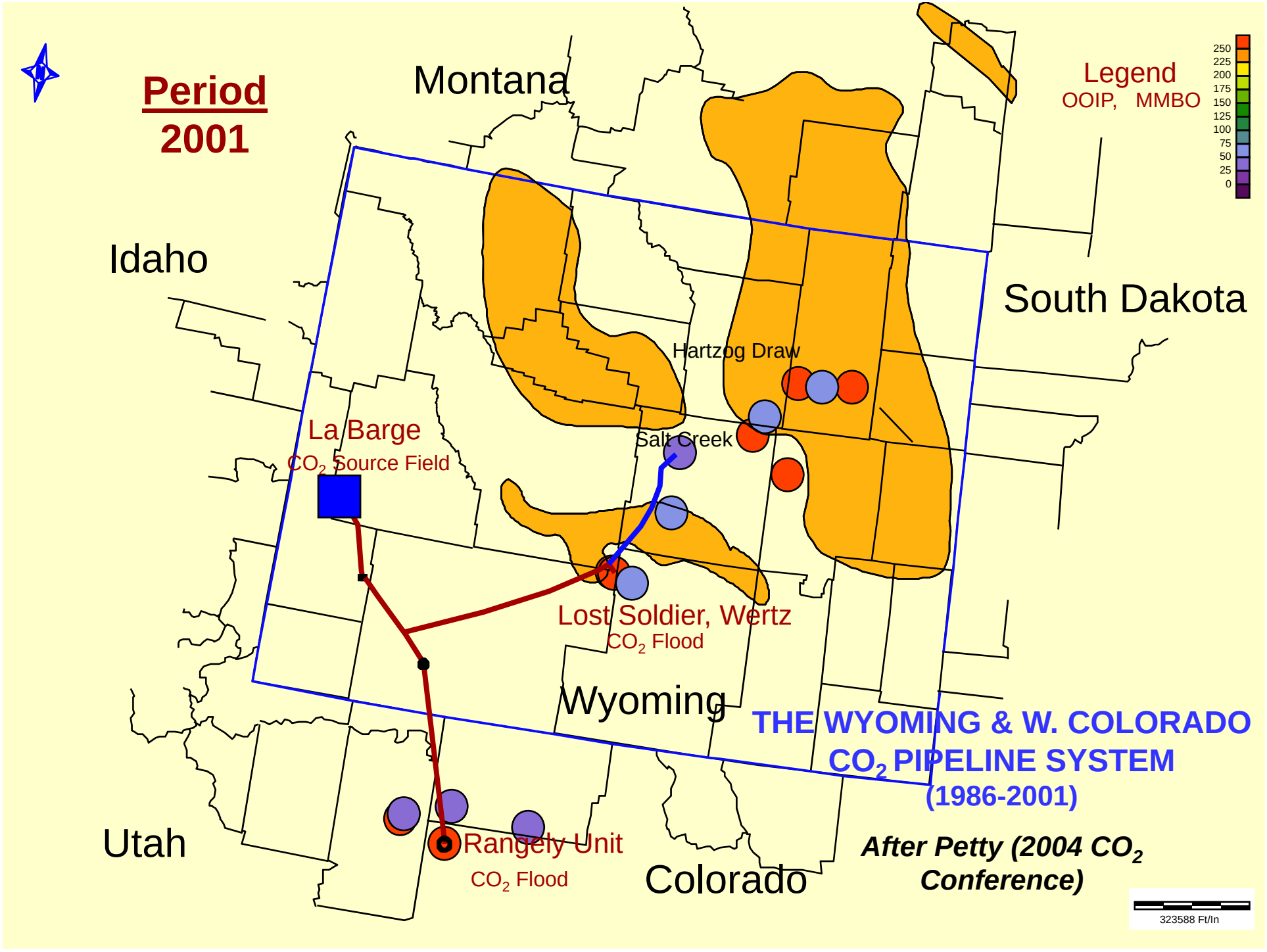
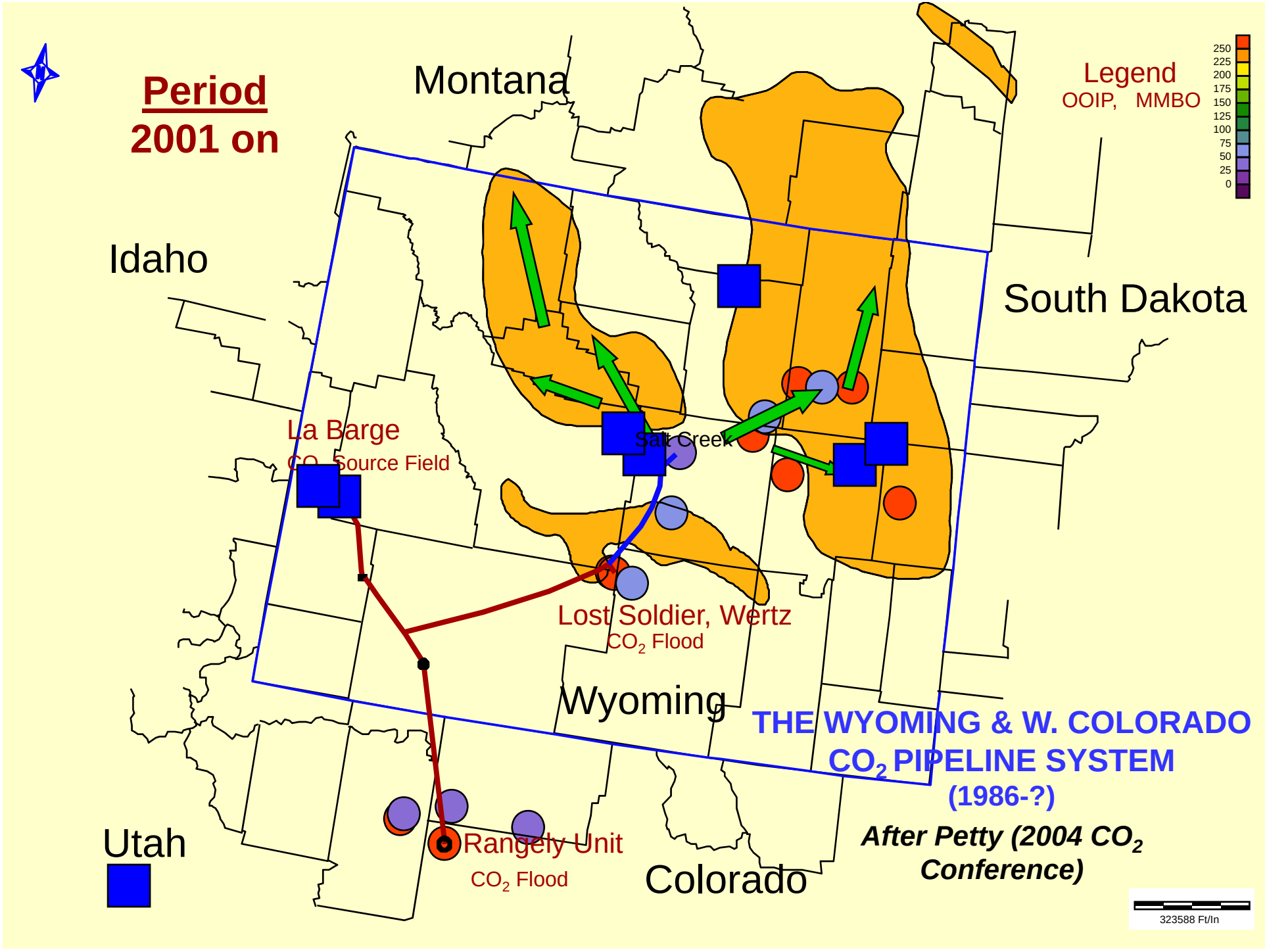

Period
2001
Montana
Idaho
South Dakota
Wyoming
Utah
Colorado
Legend
OOIP, MMBO
250
225
200
175
150
125
100
75
50
25
0
Hartzog Draw
Salt Creek
La Barge
CO2 Source Field
Lost Soldier, Wertz
CO2 Flood
Rangely Unit
CO2 Flood
THE WYOMING & W. COLORADO
CO2 PIPELINE SYSTEM
(1986-2001)
After Petty (2004 CO2 Conference)
323588 Ft/In


Period
2001 on
Montana
Idaho
South Dakota
Legend
OOIP, MMBO
250
225
200
175
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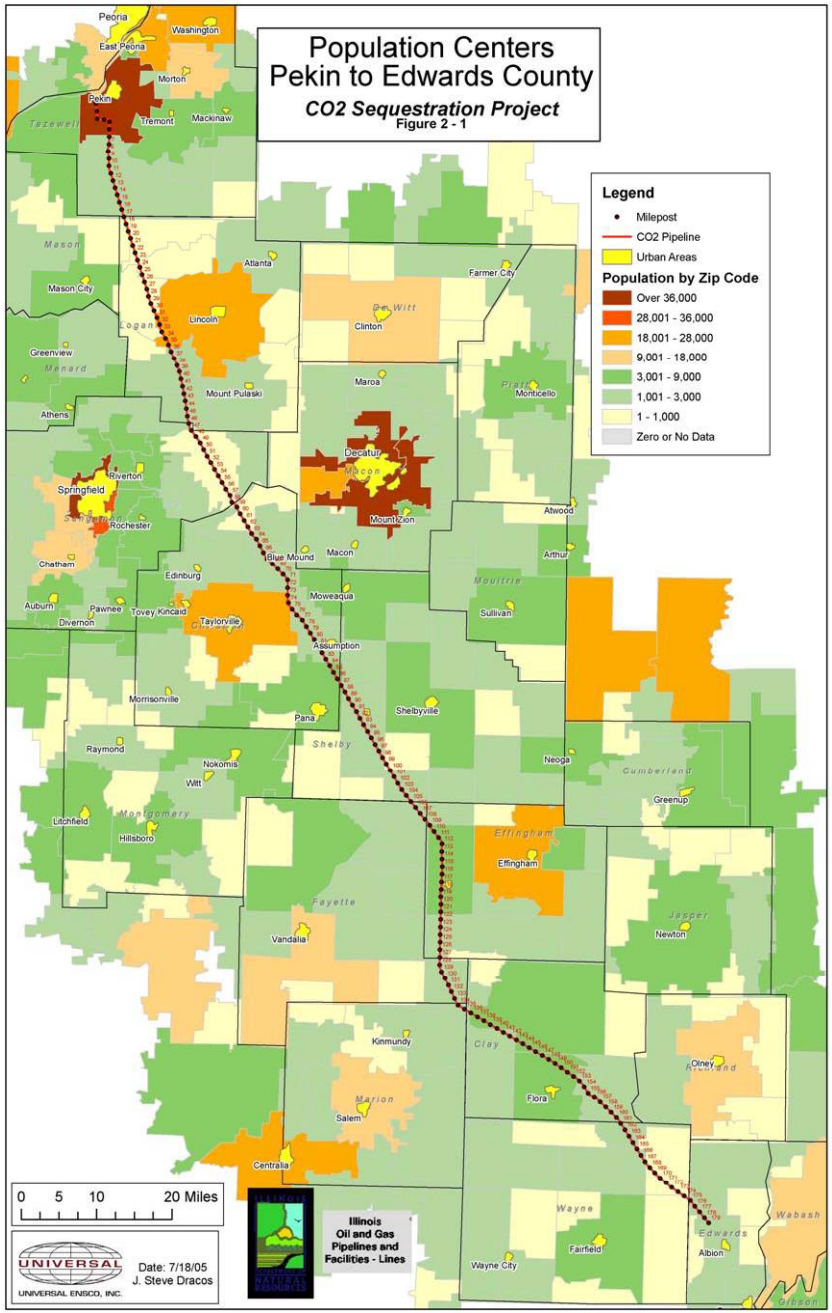
125
100
75
50
25
0
La Barge
CO2 Source Field
Salt Creek
Lost Soldier, Wertz
CO2 Flood
Wyoming
THE WYOMING & W. COLORADO
CO2 PIPELINE SYSTEM
(1986-?)
After Petty (2004 CO2
Conference)
Utah
Rangely Unit
CO2 Flood
Colorado
323588 Ft/In

EXAMPLE NETWORKS
(PLANNED)

Kinder Morgan's Proposed Sasquatch CO_2 Pipeline; Alberta, Canada

Re: KM Personal Communication - 2007



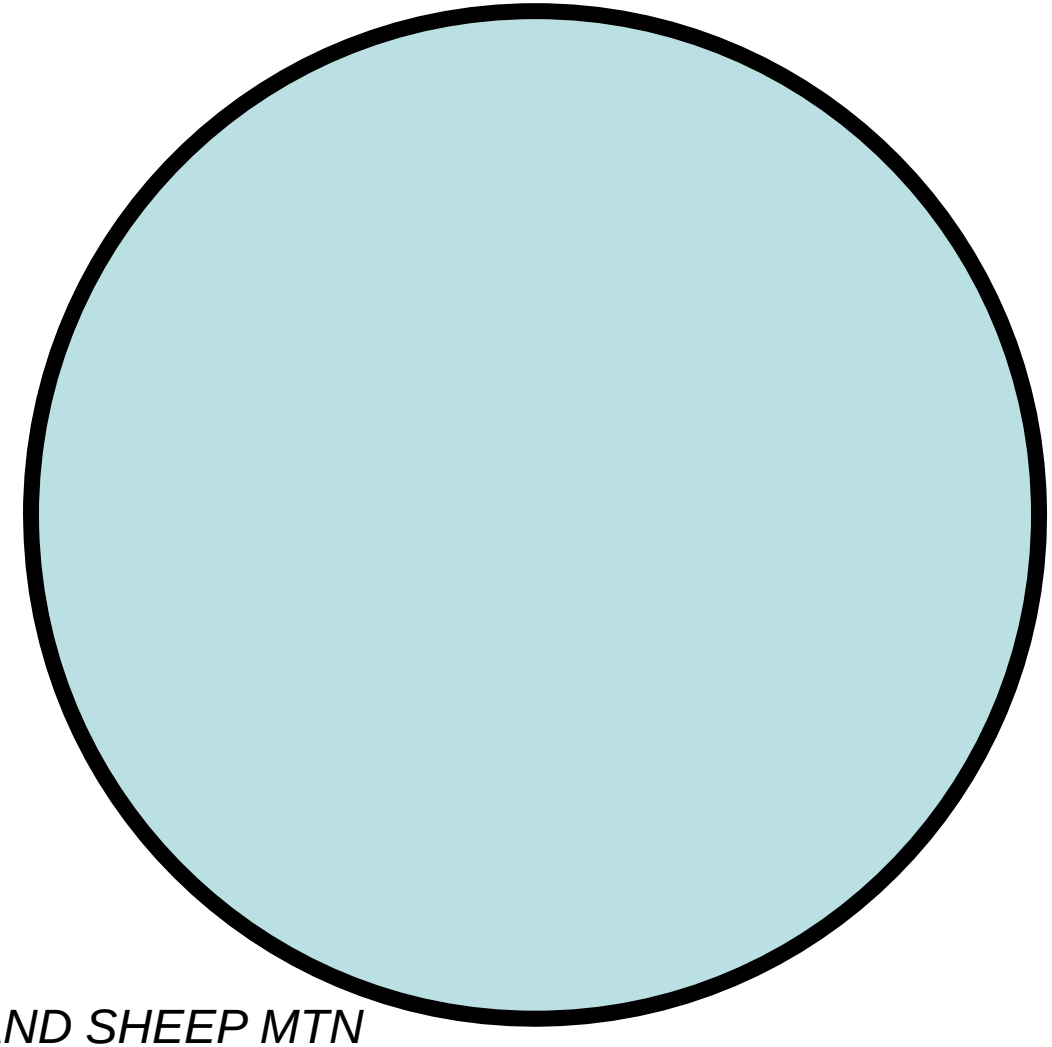
Ref: Illinois Geological Survey - 2007

Illinois Example

- 180 mile pipeline
- 365 MMscf/d (7.7 million tonnes/yr) designed pipeline from a "CO_2 EOR" perspective
- Medium pressure (2,300 psig) 18-inch pipe, cost estimate is $779,444/mile
- $144 million installed

Ownership, Point-to-Point, and Open Access Issues

INDIVIDUAL or COMMON OWNERSHIP



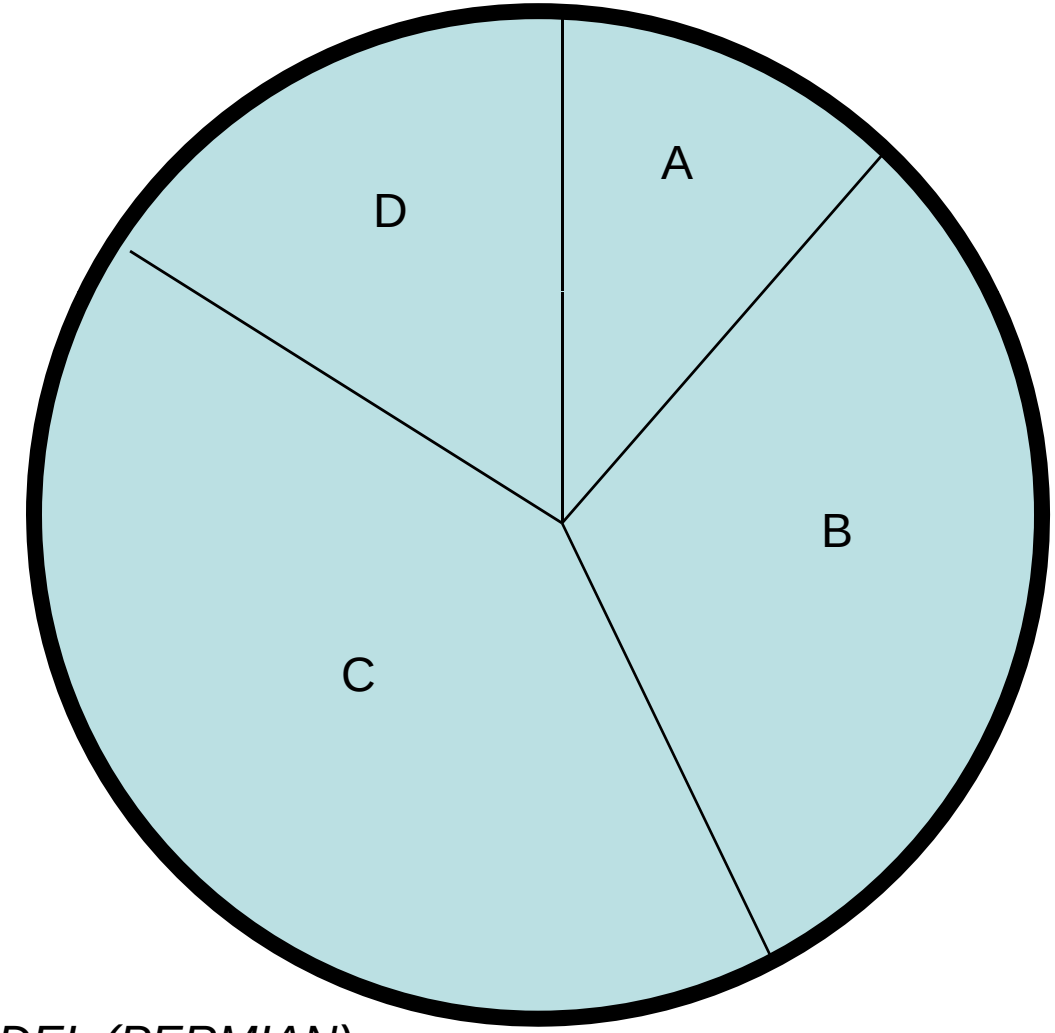
CAPACITIES CONTRACTED BY PL OWNER(s)/ OPERATOR

COMMON TARIFFs FOR EACH TRANSPORTER

PRIVATE PIPELINE, NO OPEN ACCESS

BRAVO AND SHEEP MTN MODELS (PERMIAN)

DIVIDED OWNERSHIP (a)



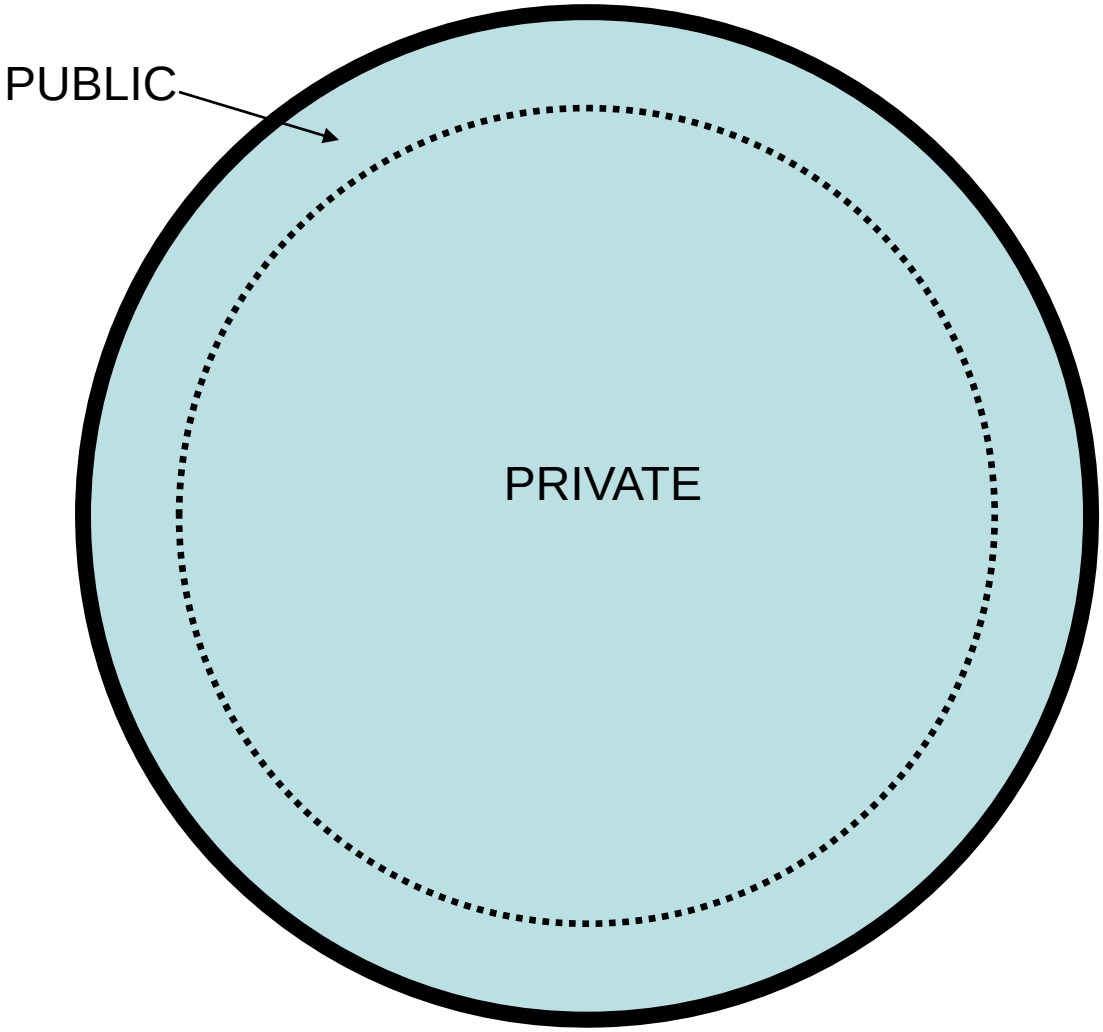
CAPACITIES CONTRACTED BY EACH OWNER

SEPARATE TARIFFs FOR EACH OWNER

PRIVATE PIPELINE, NO OPEN ACCESS

ESTE MODEL (PERMIAN)

DIVIDED OWNERSHIP (b)



CAPACITIES CONTRACTED BY EACH OWNER

SEPARATE TARIFFs FOR EACH OWNER

FOR PRIVATE PORTION, NO OPEN ACCESS

ACCOMODATION FOR GROWTH

FOR ‘PUBLIC’ PORTION, OPEN ACCESS

ALBERTA MODEL?

FACILATORS AND ROLES

- INDUSTRY
  - PAST SOURCE-TO-SINK MODELS DOMINATE
  - BUT EXCEPTIONS DO EXIST
  - SEPARATE PL COMPANIES AS FACILITATORS
- QUASI-GOVERNMENT
  - WYOMING PIPELINE AUTHORITY MODEL

- GOVERNMENT ROLES
  - CAPACITY ENHANCEMENTS (OWNERSHIP)
  - ROW ASSISTANCE
    - EMINENT DOMAIN
      - TRANS TEXAS CORRIDOR MODEL

LIST OF PL FACILATORS

(FOR **TYPES II AND III** {PARTIAL?})

- KINDER MORGAN
- TRINITY CO_2
- BLUE SOURCE
- EL PASO (CIG)
- PENN WEST
- ENBRIDGE
- SEMPRA
- SEMGROUP

Contact Information

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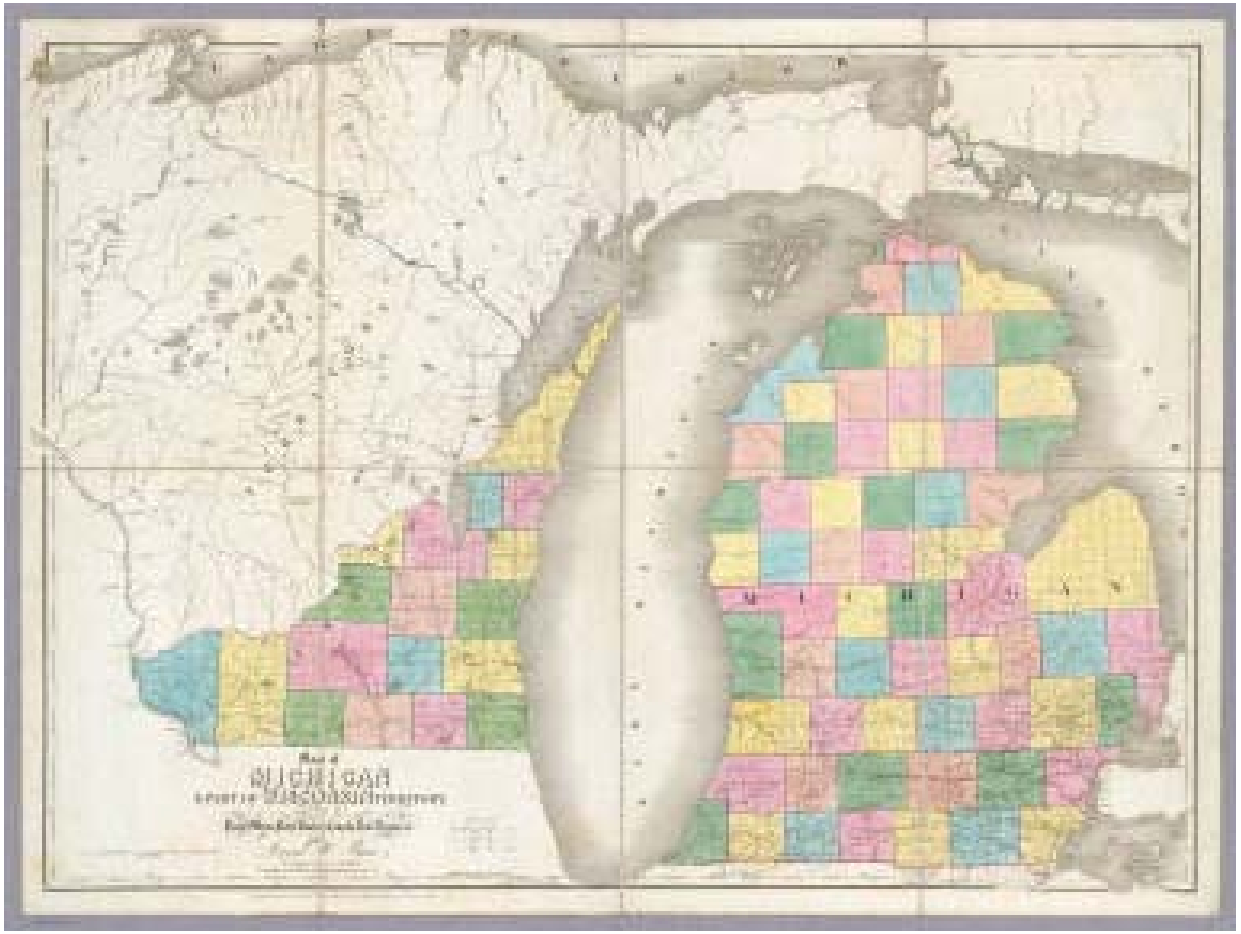
If Technical Criteria Come First?

Then An Interesting Sidebar Discussion Should be Entertained (Time Permitting)

A Quick Look at Your Neighbor to the East



Ref: Map of Michigan & Part Of Wisconsin Territory, Exhibiting the Post Offices, Post Roads, Canals, Rail Roads, &c. By David H. Burr. (Late Topographer to the Post Office.) Geographer to the House of Representatives of the U.S. John Arrowsmith. Entered ... July 10th, 1839, by David H. Burr ... District of Columbia. Author: Burr, David H., 1803-1875 Date: 1839

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Michigan CO_2 Enhanced Oil Recovery

"A well kept secret"

Robert G. Mannes

CORE ENERGY, LLC

Presented at the 2003 CO_2 Flooding Conference in Midland, Tx
Dec '03

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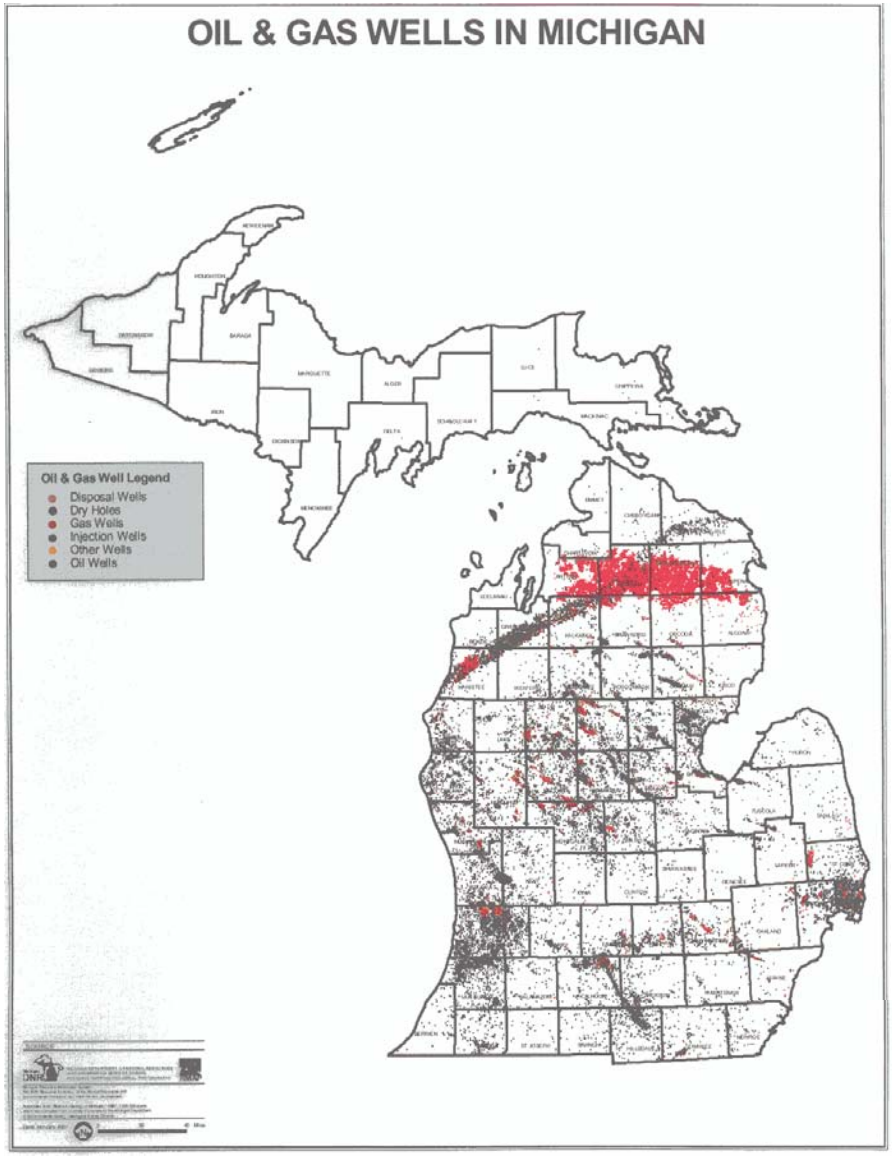
Michigan at a Glance



- 17th in oil production
- 11th in natural gas production
- 18th in oil wells drilled
- 9th in natural gas wells drilled
- 54 active gas storage fields
- 600 Bcf working storage capacity

Cumulative Production through 2002:

- 1.238 Billion Barrels of Oil
- 6.083 Trillion Cubic Feet of Gas

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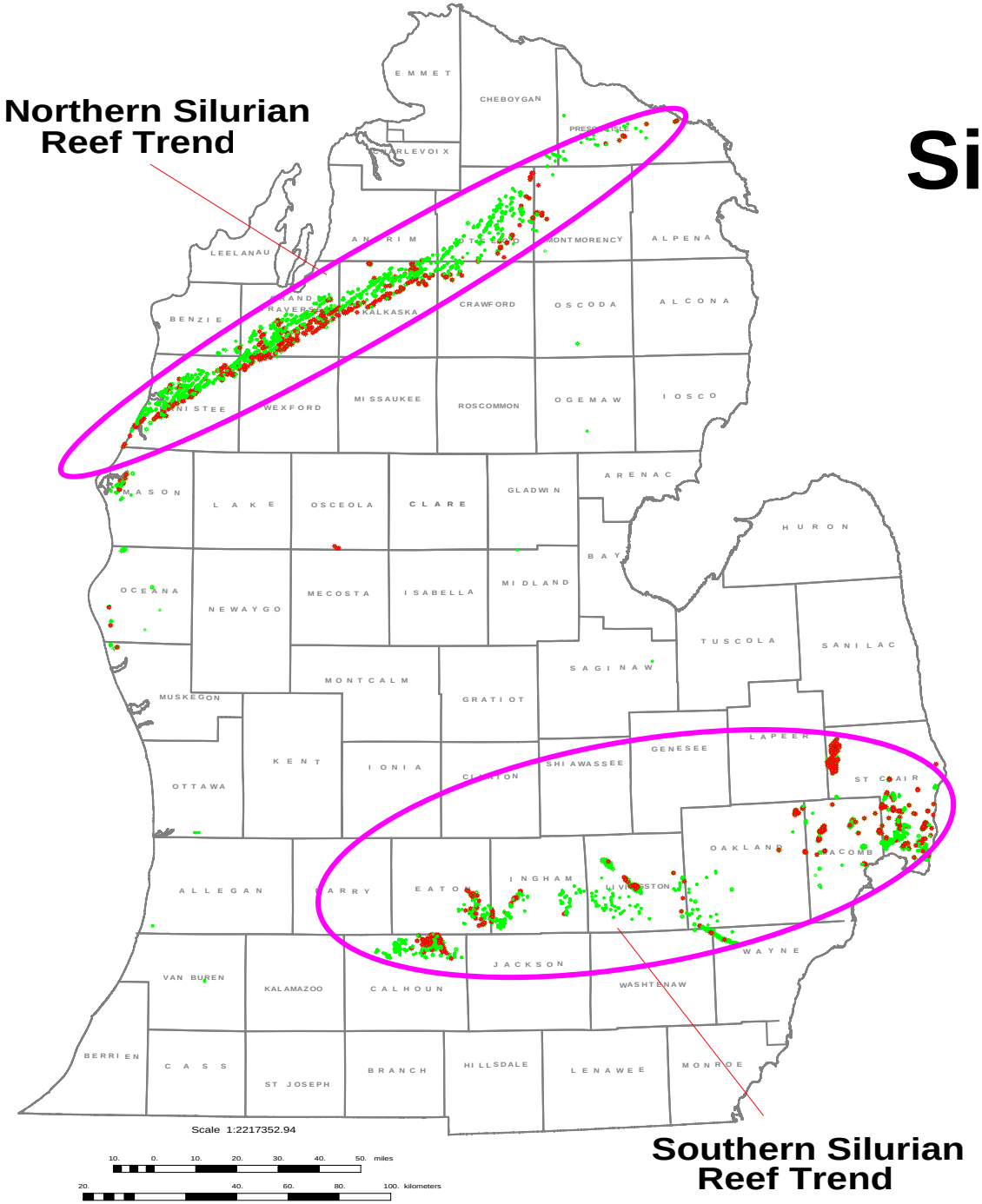
Michigan Silurian Reefs

- GAS
- OIL



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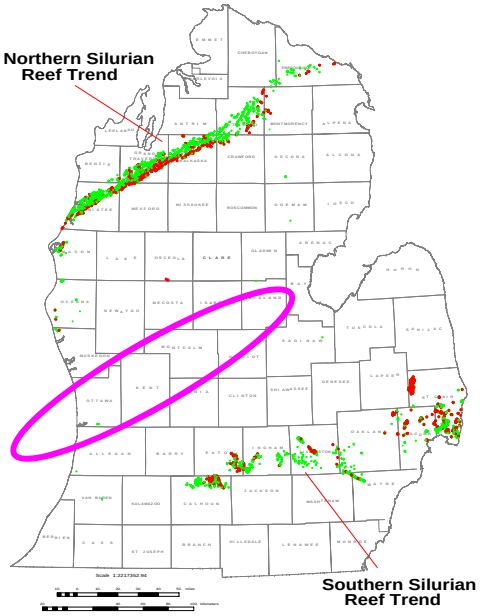

- Over 650 Separate Reefs
- 390 Million BO and 2.2 TCF gas produced
- 34% avg. primary recovery
- only a limited number of waterflood attempts

Northern Reef Trend

Key Engineering Properties - Northern Trend	
Thickness	150 to 700 ft
Average Porosity (Range)	7% (3 to 18%)
Average Permeability (Range)	12 md (0.1 md to 8 darcies)
Oil Gravity	40º to 42º api on average
Average Reservoir Temperature	100º to 120º F
Oil Formation Volume Factor	1.2 to 1.6
Lithology	Dolomite and/or Limestone
Average depths to top of reservoirs	4500 to 6000 ft

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Bottom Line – Spectacular Tertiary Recovery and Sequestration Targets

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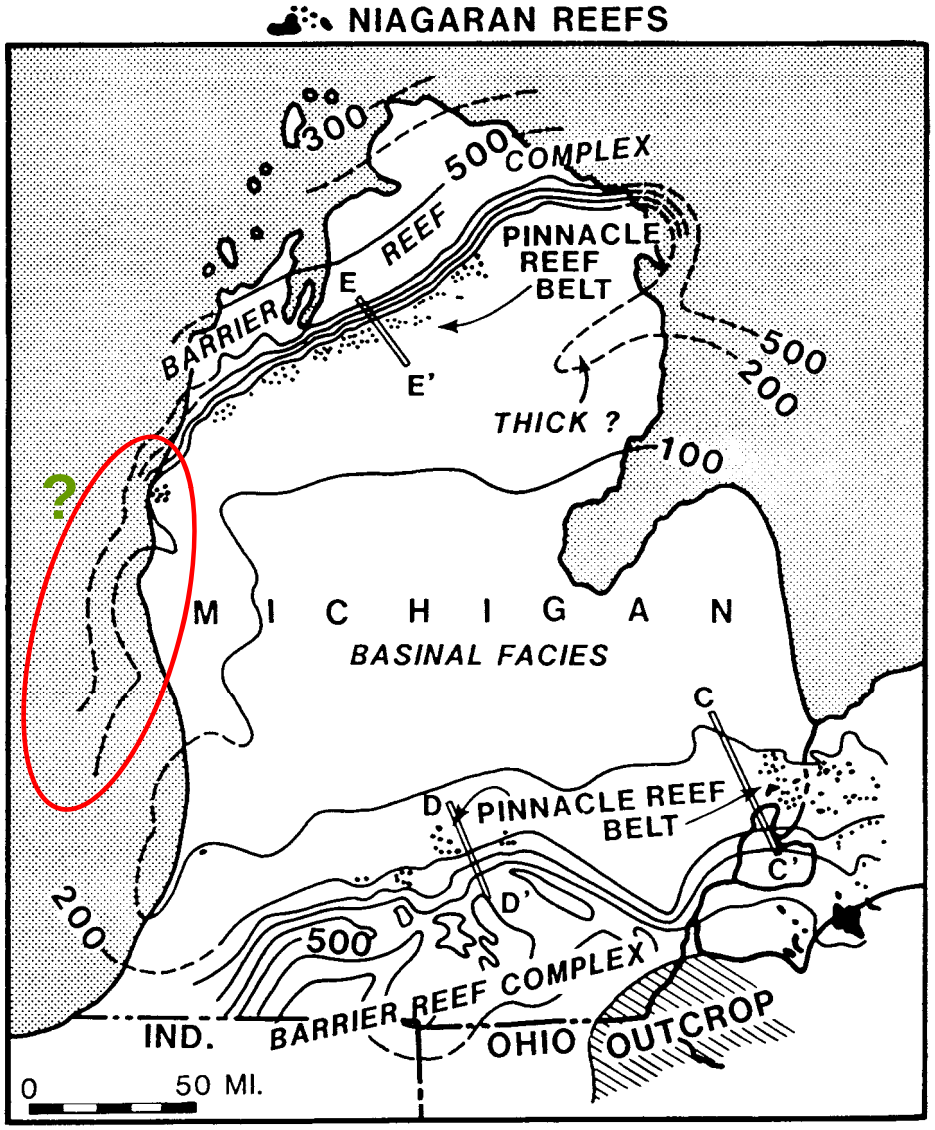
Isopach map of Niagaran rocks in the Michigan basin showing three depositional areas; contour interval 100 feet (from Gardner and Bray, 1984). Stipple pattern area is Lake Huron (east) and Lake Michigan (west). North is toward the top of the page.



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QUESTIONS??